Effects of Soluble Salts on Coating Life in Atmospheric Services

The authors describe the results of 14 years of exposure testing in urban, rural, and industrial atmospheres and more than 4 years of testing in marine atmospheres.

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The detrimental effect of water-soluble contaminants at the steel/paint interface is well known. The presence of these species at the steel/paint interface can promote osmotic blistering of the coating and underfilm corrosion of the steel. Both processes lead to the deterioration of the paint system in very short periods of time.

Although this is a long-standing problem, numerous questions remain. This article attempts to answer some questions about the effect of salt contaminant concentration, atmospheric conditions (rural, urban, and industrial atmospheres), and marine conditions on coating life. Part I of this article describes results of 14 years of research conducted in outdoor atmospheric testing stations on steel contaminated with chlorides or sulfates. Part II of the present article describes 4.5 years of research on salt-contaminated steel in marine atmospheric exposures (Fig. 1).

Survey of Earlier Studies

The presence of water-soluble contaminants (particularly sulfates and chlorides) at the steel/paint interface is known to have detrimental effects on the integrity of most paint systems.[1-2] Rust development under the paint film and osmotic blistering are commonly observed at an early stage in paint coatings applied over contaminated steel.[3]

Are there guidance levels for soluble salt concentrations above which unacceptably fast deterioration of paint films starts to occur? So it seems, judging by the results of some studies.[4] Table 1 shows the critical salt concentration thresholds reported by several authors.[2,5-10] As can be seen, the results are somewhat disperse, which is logical considering that they were obtained by using different experimental methodologies on different paint systems. Nevertheless, Table 1 allows 2 major conclusions to be drawn.

Fig. 1 - Marine environment paint testing raft. The atmospheric exposure test rack can be seen on the deck at center-left.

• Critical salt levels, expressed as surface concentrations (mg/m^2), are higher for sulfate than for chloride, suggesting that such levels are somewhat determined by the presence of a given number of contaminant molecules at the paint/steel interface. Sulfate molecular weight is more than twice the molecular weight of chloride.
• Such critical concentrations are a function of the paint film thickness; the thinner the film, the lower the contaminant concentration required to induce early deterioration of the coating.

ISO/TC/SC12/WG5 has for some time been trying to develop a standard for critical salt concentration thresholds.[11]

A precise knowledge of saline concentration critical levels would be of great use in dealing with painting of contaminated steel. Such critical levels should reasonably depend not only on the contaminant concerned and the thickness of the paint system, but also on the type of coating and the conditions to which the coating is to be exposed during its service operation.

The present article summarizes the results obtained to date in the urban, rural, and industrial atmospheric exposure studies undertaken 14 years ago by the National Metallurgical Research Centre of Spain. The present article also summarizes 4.5 years of results of marine atmospheric exposure studies.[12,13]

Part I: Atmospheric Exposure Testing

Experimental

Specimens of 12.5 cm x 25 cm were prepared from hot-rolled steel plate, 3 mm thick, with intact millscale (grade A of the Swedish standard SIS 055900-1967 [SSPC-VIS 1, Visual Standard for Abrasive Blast Cleaned Steel]). The specimens were subsequently cleaned by shot blasting (S-280) to the ASa3 grade (SSPC-SP 5, White Metal Blast Cleaning). The presence of salt contamination at the steel/paint interface was simulated by dosing freshly blasted panels with variable amounts of $FeSO_4$ and NaCl (Table 2) from solutions of these compounds in a mixture of distilled water and methanol. The alcohol was used to promote evaporation of the solvent and to minimize early formation of rust on the underlying steel.

Fig. 2 - The epoxy/polyurethane paint system is sensitive to chloride contamination (303.4 mg/m^2) at all film thicknesses.

A pipette was used to dose the steel panel with the appropriate volume of the contaminant solution. Immediately after the solution was applied at the center of the panel, it was spread on the whole test surface with a small glass rod to produce as uniform a film as possible. Then, the panels were dried in a stove to further control the formation of rust on the steel surface.

Subsequently, different paint systems were applied (Tables 3 and 4). Once dry, the painted panels were exposed to different atmospheres (rural, urban, and industrial).

As control specimens, freshly blasted steel panels without any contamination at the steel/paint interface were used.

Regular inspections of rusting and blistering grades shown on painted surfaces were carried out. Failure was evaluated according to ASTM D 610 (Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces) and ASTM D 714 (Standard Test Method for Evaluating Degree of Blistering of Paints), respectively. Undercutting was also evaluated, but no significant effect of contaminant on paint delamination at the scribe was found. Some replicates were used in the study but in such cases, no differences between replicates were found.

Results

For all coating materials, the deterioration of the paint coating initially manifests itself through a fine blistering (8-9 MD-D of ASTM D 714) on the whole surface of the specimen. This fine blistering is on occasion difficult to observe. In some systems, the deterioration has already appeared within the first months of exposure to the atmosphere. In other systems, the deterioration takes longer to appear.

The type of atmosphere and the thickness of the coat also play a role in the amount of time needed for the phenomenon to appear.

Later, depending upon the type of paint system and type of exposure, the blisters either stabilize or progress very slowly, or they may increase, even bursting open, due to the accumulation of oxide on their interior.

Figs. 2-4 show examples of conditions of the test specimens after 14 years of exposure in the different atmospheres.

Table 1
Critical Thresholds for Chloride and Sulfate that Result in Early Deterioration of Paint Coatings [Refs. 2, 5-10]

Reference	Dry film thickness*	Cl^- (mg/m^2)**	$SO_4^=$ (mg/m^2)
Boocock [Ref. 2]	125-225 µm	70-300	700-3,000
Sonntag [Ref. 5]	25-35 µm	>10	—
Koehler [Ref. 6]	7-11 µm	60-250	90-350
West [Ref. 7]	thin films 250 µm	70 500	160 500
Mayne [Ref. 8]	100-150 µm	—	588
Morcillo et al. [Ref. 9]	60-190 µm	60-300	1,000-2,500
Weldon [Ref. 10]	130-180 µm	50-100	500-1,000

** 1 mil = 25.4 micrometers (µm)*
*** 1 mg/m^2 = 0.1 $\mu g/cm^2$*

Table 2
Salt Contamination Tested in Part I (mg/m^2)

NaCl	(Cl^-)	$FeSO_4$	($SO_4^=$)
20	(12.1)	150	(94.7)
100	(60.7)	250	(157.9)
500	(303.4)	500	(315.8)

Discussion

Chloride Contamination

From the analysis of Tables 5-7, it is observed that chloride contamination, at the highest concentration (303.4 mg/m^2), does not seem to be tolerated by the different paint systems tested, except for the zinc silicate priming systems. Deterioration at this contamination level appears to a greater or lesser degree in practically all of the film thicknesses tested, independent of the type of atmosphere in which they were exposed.

The tolerance of the zinc-rich coating for saline contamination at the interface is in agreement with an idea pointed out by Evans.[14] He suggested that a high metallic zinc content in the paint could counteract the harmful effects of contamination. The formation of rust on the specimens coated with zinc-rich primer after 14 years of exposure is not due to interfacial contamination. The same rust formation is found on uncontaminated specimens. The exhaustion of the coating in terms of its capacity to provide cathodic protection could be the cause of rust formation on this type of coating.

The chlorinated rubber system stands out from the rest with regard to its intolerance to chloride interfacial contamination. As the exposure time increases, deterioration affects even the specimens contaminated at the lowest level (12.1 mg/m^2).

The polyurethane system also shows degradation at the intermediate level of 60.7 mg/m^2, although this was recorded only in the rural atmosphere. The reason for this peculiar behavior may lie in the high times of wetness (TOW) presented by this particular testing station, due to its proximity to a marsh.

As has been mentioned before, deterioration begins relatively quickly in most of

Table 3
Characteristics of Paint Systems Applied in Rural, Urban, and Industrial Atmospheres

Paint System	Primer	Intermediate	Topcoat	Remarks
Oil 1/Alkyd	INTA* 164101	—	INTA 164218	Primer: zinc chromate/iron oxide
Oil 2/Alkyd	INTA 164103	—	INTA 164218	Primer: red lead
Alkyd	INTA 164201	—	INTA 164218	Primer: zinc chromate/iron oxide
Chlorinated rubber	INTA 164705	INTA 164701A	INTA 164704A	Primer: red lead/red iron oxide
Vinyl	INTA 164604	INTA 164602A	INTA 164603A	Primer: zinc tetroxichromate
Polyurethane	RENFE** 03.323.125			Primer: zinc chromate in aromatic polyurethane Intermediate: aromatic polyurethane Topcoat: aliphatic polyurethane
Epoxy/Polyurethane	MIL C-82407***	RENFE 03.323.125		Primer: epoxy polyamide Intermediate: aromatic polyurethane Topcoat: aliphatic polyurethane
Zinc silicate (ZS)	INTA 164408	—	—	Primer: ethyl silicate
ZS/Chlorinated rubber	INTA 164408	INTA 164701A	INTA 164704A	
ZS/Vinyl	INTA 164408	INTA 164602A	INTA 164603A	

** Instituto Nacional de Técnica Aerospacial Standards (Madrid, Spain)*

*** Red Nacional de Ferrocarriles Españoles Standards (Madrid, Spain)*

**** MIL C-82407 (CG), "Coating, Epoxy, for Steel Structures," Military Specification (U.S.), July 23, 1968*

the paint systems tested. It starts with a fine blistering of the paint film, preferentially in the lowest film thicknesses, affecting the entire painted surface.

In some systems, depending on the nature of the coating, the blisters can burst with the emergence of rust on the surface of the paint. Once again, this fault is more likely to appear in coatings of lower thicknesses. After this, deterioration progresses more slowly (an increase in the size or frequency of blisters and the appearance of many signs of rust formation) or even stabilizes.

Tables 5-7 show blistering and rusting based on contaminant level and exposure time for the different paint systems in the different atmospheres. For instance, chlorinated rubber and polyurethane blister at 12.1-60.7 and 12.1 mg Cl^-/m^2 respectively after 14 years of atmospheric exposure (Table 5).

Chloride interfacial contamination (303.4 mg Cl^-/m^2) supposes a high risk for the integrity of most of the paint systems exposed in atmospheric service conditions. As noted above, the chlorinated rubber and polyurethane systems tested are also sensitive to lower contaminant levels.

This research raises doubts about whether chloride contaminations between 60.7 and 303.4 mg Cl^-/m^2 cause damage to most of the oil-alkyd, alkyd, vinyl, and epoxy-polyurethane paint systems. It can also be concluded that all the paint systems with zinc-rich primer seem to resist blistering, at least up to the maximum contaminations analyzed in this study (303.4 mg/m^2).

Sulfate Contamination

Sulfate contamination (94.7-315.8 mg $SO_4^=/m^2$) does not seem to affect the integrity of the different paint systems tested,

Table 4
DFTs of Paint Systems Applied in Rural, Urban, and Industrial Atmospheres

	Dry Film Thicknesses (dfts) Tested, µm*			
Paint Systems	**a**	**b**	**c**	**d**
Oil 1/Alkyd	90	125	175	250
Oil 2/Alkyd	65	100	130	—
Alkyd	65	95	125	—
Chlorinated rubber	75	95	130	—
Vinyl	60	90	120	150
Polyurethane	120	150	—	—
Epoxy/Polyurethane	100	150	190	—
Zinc silicate	60	95	—	—
Zinc silicate/Chlorinated rubber	80	110	140	—
Zinc silicate/Vinyl	100	120	150	—

** 1 mil = 25.4 micrometers (µm)*

at least not during the first 8 years of atmospheric exposure.

The chlorinated rubber system (at any of the 3 concentrations tested) and the vinyl and epoxy-polyurethane systems (at the highest concentration tested, 315.8 mg/m^2) occasionally experienced film blistering, although it is true that this deterioration process is very slow and takes a long time (14 years) to become perceptible to the naked eye.

The vinyl and epoxy-polyurethane systems show blistering and rusting, although only at the highest contamination level (315.8 mg/m^2) and not in all the testing conditions (thickness, type of atmosphere, etc.).

In the oil type-priming systems (Oil 1 or 2/Alkyd), blistering and rusting do not appear. These paint systems show a severe cracking of the film after 14 years of exposure in the industrial atmosphere (Table 8).

Surprisingly, the phenomenon did not appear when the contaminant was $FeSO_4$, precisely the contaminant mentioned most in the literature. It was conjectured that the concentration of $SO_4^=$ deposited on the interface (94.7-315.8 mg/m^2) was not sufficient to bring on the phenomenon. Thus, new specimens were prepared, with $SO_4^=$ contamination levels of 500, 1,000, and 2,500 mg/m^2.

New coatings were applied on these specimens, and they were exposed to 2 marine atmospheres included in another test program carried out in coastal locations. The results obtained after 4.5 years of exposure are shown in Part II of the paper.

Summarizing the results, it is seen that oil/alkyd, alkyd, polyurethane, and zinc-rich primed systems seem to tolerate sulfate contaminations, provided the concentration is at most 315.8 mg/m^2.

Part II: Marine Exposure Testing

In Part I of this article, mention has been made of the considerations that led to the research into the effects of soluble salts on

Table 5
Results Obtained in the Rural Atmosphere at Different Times of Exposure

Paint System	4 years				8 years				14 years			
	N.C.	Chlorides, mg/m²			N.C.	Chlorides, mg/m²			N.C.	Chlorides, mg/m²		
		12.1	60.7	303.4		12.1	60.7	303.4		12.1	60.7	303.4
Oil 1/Alkyd	—	—	—	B c,d	—	—	—	B c,d	—	—	—	B c,d
Oil 2/Alkyd	—	—	—	B a,b,c	—	—	—	B a,b,c	—	—	—	B a,b,c R a
Alkyd	—	—	—	B a,b,c	—	—	—	B a,b,c	—	—	—	B a,b,c R a,b
Chlorinated rubber	—	—	—	B a,b,c R a,b,c	—	—	—	B a,b,c R a,b,c	—	B a,b,c R a	B a,b,c R a	B a,b,c R a,b,c
Vinyl	—	—	—	B a,b,c,d R a,b,c,d	—	—	—	B a,b,c,d R a,b,c,d	—	—	—	B a,b,c,d R a,b,c,d
Polyurethane	—	—	B a,b	B a,b	—	—	B a,b	B a,b R a	—	B a	B a,b	B a,b R a,b
Epoxy/Polyurethane	—	—	—	B a,b,c	—	—	—	B a,b,c	—	—	—	B a,b,c R a
Zinc silicate (ZS)	—	—	—	—	—	—	—	—	R a,b	R a,b	R a,b	R a,b
ZS/Chl. rubber	—	—	—	—	—	—	—	—	—	—	—	—
ZS/Vinyl	—	—	—	—	—	—	—	—	—	—	—	—

N.C. = Not contaminated
— = No effect observed
B = Blistering
R = Rusting
a,b,c,d: See Table 4

coating life, in particular the definition of contamination guidance levels for steel surfaces before the application of paints and related products.

In the research described in Part I, which was started in 1982, consideration was made of exposure in rural, urban, and industrial atmospheres. At that time, the National Metallurgical Research Centre (CENIM) did not have a marine exposure testing station in order to evaluate the harmful effect of soluble salts on paint systems.

It was later decided to undertake a study in marine environments, considering 3 exposure conditions corresponding to marine atmosphere, total immersion in sea water, and alternate immersion.

Previous experience, obtained during the study described in the first part of this article, helped to improve the definition of the saline levels to be tested. Chloride levels of 5, 10, 25, and 100 mg/m^2 were selected compared to 12, 60, and 300 mg/m^2 in the industrial, urban, and rural atmospheres. The sulfate levels were increased to 500, 1,000, and 2,500 mg/m^2 compared to approximately 100, 150, and 300 mg/m^2 in the earlier study. Another modification was to include panels with rust at the coating/metal interface in addition to blast-cleaned panels. This effect was analyzed only in conditions of total immersion in sea water.

With this general outline, the research project started. The present discussion focuses on results from marine atmospheric exposure; immersion data are available from the authors and will be published later.

Fig. 3 - (left) The zinc silicate system is not sensitive to chloride contamination. The slight rusting seen in the photograph cannot be attributed to saline interfacial contamination.

Fig. 4 - (right) The zinc silicate/vinyl system is not sensitive to chloride contamination. The vinyl topcoat shows considerable chalking.

Experimental

Specimens of 12.5 cm x 25 cm were prepared from hot-rolled steel plate, 3 mm thick, with intact millscale (grade A of the Swedish standards SIS 055900-1967 [SSPC-VIS 1]). The specimens were subsequently cleaned by shot blasting (S-280) to the ASa3 grade (SSPC-SP 5).

The presence of rust at the steel/paint interface is achieved by exposing grade A specimens to an uncontaminated rural atmosphere, with the apparent absence of sulfate- or chloride-type atmospheric contaminants, until grade B rusting is achieved. Subsequently, surface condition BSa2 is obtained by centrifugal blasting with type S-280 shot abrasive. (According to SIS 055900, "almost all mill scale, rust, and foreign matter should be removed." However, some rust still remains on the surface.)

The panels were dosed with soluble salt solutions (Table 9) in the same way that the panels for industrial, urban, and rural exposures were dosed.

Subsequently, different paint systems (proprietary products) were applied at different dry film thicknesses (Table 10). The different paint systems were applied scrupulously following the technical specifications of the paint manufacturers.

To prevent the attack of the edges of the test specimens, an additional layer of paint was applied by immersion in a bath containing an appropriate thixotropic paint.

Figure 1 shows a photograph of one of the marine testing rafts. As can be seen, the raft incorporates a rack for atmospheric testing.

Regular inspections of rusting and blistering grades shown on painted surfaces were carried out. Failure was again evaluated according to ASTM D 610 and ASTM D 714 standards, respectively.

Results

The study was concluded after 4.5 years. Table 11 displays the results from marine atmospheric exposure, indicating the conditions which led to blistering (B) and rusting (R), as well as the time for the appearance of the deterioration phenomenon.

Data on total and alternate immersion are available from the authors.

Table 6
Results Obtained in the Urban Atmosphere at Different Times of Exposure

Paint System	4 years				8 years				14 years			
		Chlorides, mg/m²				Chlorides, mg/m²				Chlorides, mg/m²		
		12.1	60.7	303.4		12.1	60.7	303.4		12.1	60.7	303.4
Oil 1/Alkyd	—	—	—	B d	—	—	—	B d	—	—	—	B d
Oil 2/Alkyd	—	—	—	B a,b,c R a,b	—	—	—	B a,b,c R a,b	—	—	—	B a,b,c
Alkyd	—	—	—	B a,b	—	—	—	B a,b R b	—	R a	—	B a,b R a
Chlorinated rubber	—	—	B a	B a,b,c R a,b,c	—	B a,b	B a	B a,b,c R a,b,c	B a,b	B a,b R a	B a R a,b	B a,b,c R a,b,c
Vinyl	—	—	—	B b,c,d	—	—	—	B a,b,c,d R b	—	—	—	B a,b,c,d R a,b
Polyurethane	—	—	—	B a,b	—	—	—	B a,b R a,b	—	—	—	B a,b R a,b
Epoxy/Polyurethane	—	—	—	B a,b,c	—	—	—	B a,b,c	—	—	—	B a,b,c R b,c
Zinc silicate (ZS)	—	—	—	—	—	—	—	—	R a,b	R a,b	R a,b	R a,b
ZS/Chl. rubber	—	—	—	—	—	—	—	—	—	—	—	—
ZS/Vinyl	—	—	—	—	—	—	—	—	—	—	—	—

N.C. = Not contaminated
— = No effect observed
B = Blistering
R = Rusting
a,b,c,d: See Table 4

Discussion

Chlorides

With regard to chloride contamination, the results obtained in the marine atmospheres (Table 11) clearly indicate the appearance of blistering only in the alkyd system applied on the highest of the tested contaminations (100 mg/m^2). Blistering begins relatively late, after 4 years, and affects the 2 film thicknesses considered in the study (Table 10). Rusting is also observed in low thickness chlorinated rubber/acrylic systems at 100 mg Cl^-/m^2.

Sulfates

With regard to sulfate contamination (Table 11), all of the paint systems tested in the marine atmosphere show deterioration at the highest sulfate levels tested (2,500 mg/m^2). The chlorinated rubber and vinyl systems also show a certain propensity at 500 and 1,000 mg/m^2 respectively, depending on the thickness of the film. The most tolerant system is the alkyd system, which only presents deterioration at the highest contamination level (2,500 mg/m^2). Figure 5 shows 3 of the systems after 2 years of exposure to the highest sulfate contamination level.

Summarizing the results obtained in Parts I and II of this article related to sulfate contamination, it is seen that the alkyd system pigmented with zinc chromate, the polyurethane system, and the zinc-rich primer seem to tolerate sulfate contaminations, provided the concentration is no greater than about 300 mg/m^2. As the contamination increases (300-1,000 mg/m^2), so the probabilities of the system showing premature deterioration increase, particularly

Table 7
Results Obtained in the Industrial Atmosphere at Different Times of Exposure

Paint System	4 years				8 years				14 years			
		Chlorides, mg/m²				Chlorides, mg/m²				Chlorides, mg/m²		
		12.1	60.7	303.4		12.1	60.7	303.4		12.1	60.7	303.4
Oil 1/Alkyd	—	—	—	B a,b,c,d	—	—	—	B a,b,c,d R a,b,c,d	Film destroyed by cracking			
Oil 2/Alkyd	—	—	—	B a,b,c R b,c	—	—	—	B a,b,c R a,b,c	Film destroyed by cracking			
Alkyd	—	—	—	B a,b,c R a,b	—	—	—	B a,b,c R a,b	—	—	—	B a,b,c R a,b
Chlorinated rubber	—	—	B a	B a,b,c R a,b,c	—	—	B a	B a,b,c R a,b,c	R a	R a	B a R a	B a,b,c R a,b,c
Vinyl	—	—	—	B a,b,c,d R a,b	—	—	—	B a,b,c,d R a,b,c,d	—	—	—	B a,b,c,d R a,b,c,d
Polyurethane	—	—	—	B a,b	—	—	—	B a,b	—	—	—	B a,b R a,b
Epoxy/Polyurethane	—	—	—	B a,b,c	—	—	—	B a,b,c	—	—	—	B a,b,c R a,b,c
Zinc silicate (ZS)	—	—	—	—	—	—	—	—	R a,b	R a,b	R a,b	R a,b
ZS/Chl. rubber	—	—	—	—	—	—	—	—	—	—	—	—
ZS/Vinyl	—	—	—	—	—	—	—	—	—	—	—	—

N.C. = Not contaminated
— = No effect observed
B = Blistering
R = Rusting
a,b,c,d: See Table 4

with the lowest film thicknesses. Contaminations of the order of 2,500 mg/m^2 are not tolerated by any of the systems tested. These results basically agree with some of Mayne's studies[14], which show that paint coatings on rusty steel afford good protection in the atmosphere of Cambridge, provided that the ferrous sulfate carried by the rust does not exceed the level of 938 mg/m^2.

Conclusions

Rural, Urban, and Industrial Atmospheres

Chloride interfacial contamination (303.4 mg Cl^-/m^2) supposes a high risk for the integrity of all of the paint systems exposed in atmospheric service conditions except those with a zinc silicate primer. Chlorinated rubber and polyurethane systems are also sensitive to lower contaminant levels (12.1 and 60.7 mg Cl^-/m^2).

The sulfate contamination (up to 315.8 mg $SO_4^=/m^2$) does not seem to visibly affect the integrity of the different paint systems tested, at least during the first 8 years of atmospheric exposure. However, for more prolonged exposure times (14 years), deterioration induced by sulfates has been observed at the interface in some of the paint systems, particularly at the highest contamination level (315.8 mg $SO_4^=/m^2$) and lowest dry film thicknesses.

Nevertheless, contamination levels below these ranges, particularly with lower film thicknesses than those normally specified and prolonged exposure times, may

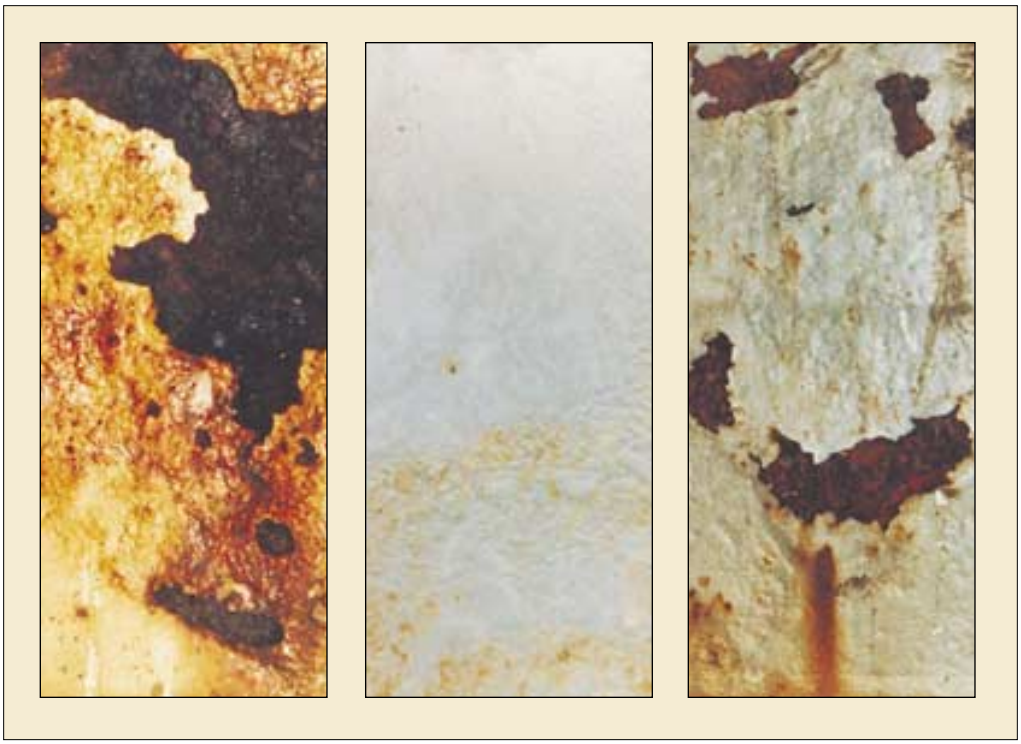

Fig. 5 - All systems tested in marine atmospheric service are sensitive to high sulfate contamination (2,500 mg/m2). Left: chlorinated rubber system (2 years); center: chlorinated rubber/acrylic system (2 years); and right: vinyl/ alkyd system (2 years).

Table 8
Summary of Results Obtained after 14 Years of Exposure in Panels Contaminated with Sulfates

	Rural Atmosphere				Urban Atmosphere				Industrial Atmosphere			
	N.C.	Sulfates, mg/m²			N.C.	Sulfates, mg/m²			N.C.	Sulfates, mg/m²		
Paint System		94.7	157.9	315.8		94.7	157.9	315.8		94.7	157.9	315.8
Oil 1/Alkyd	—	—	—	—	—	—	—	—	Film destroyed by cracking			
Oil 2/Alkyd	—	—	—	—	—	—	—	—	Film destroyed by cracking			
Alkyd	—	—	—	—	—	—	—	—	—	—	—	—
Chlorinated rubber	—	—	B a,b,c R a	—	B a,b	B a,b R a	B a,b R a,b	B a,b R a	R a	—	—	B a,b R a,b
Vinyl	—	—	—	—	—	—	—	B a	—	—	—	B a
Polyurethane	—	—	—	—	—	—	—	—	—	—	—	—
Epoxy/Polyurethane	—	—	—	B a,b	—	—	—	—	—	—	—	—
Zinc silicate (ZS)	R a,b	R a,b	R a,b	R a,b	R a,b	R a,b	R a,b	R a,b	R a,b	R a,b	R a,b	R a,b
ZS/Chl. rubber	—	—	—	—	—	—	—	—	—	—	—	—
ZS/Vinyl	—	—	—	—	—	—	—	—	—	—	—	—

N.C. = Not contaminated
— = No effect observed
B = Blistering
R = Rusting
a,b,c,d: See Table 4

Table 9
Saline Contamination Levels for Part II (mg/m^2)

NaCl	(Cl^-)	$FeSO_4$	($SO_4^=$)
8.2	(5)	791.7	(500)
16.4	(10)	1,583.3	(1,000)
41.2	(25)	3,958.3	(2,500)
164.8	(100)	—	—

Table 10
Characteristics of the Paint Systems

	Marine Atmospheres	
	Dry Film Thickness (dft) Tested, µm*	
Paint System**	a	b
Alkyd	120-140	170-190
Chlorinated rubber	100-120	180-200
Chlorinated rubber/Acrylic	90-130	200-240
Vinyl/Alkyd	130-150	200-220

** 1 mil = 25.4 micrometers (µm)*
*** Proprietary products*

also suppose a certain risk of premature failure in some paint systems.

Paint systems that incorporate a zinc silicate primer with a high zinc content seem to tolerate interfacial saline contamination analyzed in this study.

Marine Atmospheric Exposures

Interface contaminations of 500 mg/m^2 or greater of $SO_4^=$ or 100 mg/m^2 or greater of Cl^- suppose a high risk for the integrity of most of the paint systems in marine atmospheric service conditions.

Again, however, contamination levels below these ranges, particularly with smaller film thicknesses than those normally specified and prolonged exposure times, may also suppose a high risk of premature failure in some paint systems.

References

1. *B.R. Appleman, "Painting over Soluble Salts: A Perspective,"* JPCL *(October 1987), 68.*
2. *S.K. Boocock, et al., SSPC #91-07,* Effect of Surface Contaminants on Coating Life *(Pittsburgh, PA: Steel Structures Painting Council, 1992).*
3. *M. Morcillo, S. Feliu, J.C. Galván, and J.M. Bastidas, "Some Observations on Painting Contaminated Rusty Steel,"* JPCL *(September 1987), 38.*
4. *N.L. Thomas, "The Protective Action of Coatings on Rusty Steel,"* JPCL *(December 1989), 63.*
5. *Ref. 14 in L. Igetoft, "Surface Cleanliness and Durability of Anti-Corrosive Paint,"* Proc. 2nd World Congress: Coatings Systems for Bridges, *October 26-27, 1982 (Rolla, MO: University of Missouri-Rolla, 1982).*
6. *E. Koehler, "The Influence of Contaminants on the Failure of Protective Organic Coatings on Steel,"* Corrosion (NACE) *(Vol. 33, No. 6, 1977), 209.*
7. *J. West, "The Relationship between Coating Thickness and Salt Contamination on Blistering of Coatings,"* UK Corrosion/85, *Harrogate, 4-6 November 1985 (Leighton Buzzard, UK: Institute of Corrosion, 1985).*
8. *J.E.O. Mayne, "The Problem of Painting Rusty Steel,"* Journal of Applied Chemistry *(Vol. 9, 1959), 673.*

Table 11
Summary of Results Obtained in Marine Atmospheres after 4.5 Years of Exposure

Paint System	N.C.	Chlorides, mg/m^2				Sulfates, mg/m^2		
		5	10	25	100	500	1,000	2,500
Alkyd	—	—	—	—	B a (4), b (4)	—	—	B a (4) R a (4)
Chlorinated rubber (CR)	—	—	—	—	—	B a (4)	B a (4)	B a (1), b (1) R a (1), b (2)
CR/Acrylic	—	—	—	—	R a (4)	R b (3)	B a (2)	B a (2), b (2) R a (3)
Vinyl/Alkyd	—	—	—	—	—	—	B a (2), b (2) R a (3), b (4)	B a (1), b (1) R a (1), b (1)

N.C. = Not contaminated
— = No effect observed
B = Blistering
R = Rusting
a,b: See Table 10
( ) = Years for deterioration to appear

9. *M. Morcillo, S. Feliu, J.C. Galván, and J.M. Bastidas, "The Effect of Water-Soluble Contaminants at the Steel/Paint Interface on the Durability of the Paint Coating,"* JOCCA *(Vol. 71, No. 1, 1988), 11.*
10. *D.G. Weldon, et al., "The Effect of Oil, Grease, and Salts on Coating Performance,"* JPCL *(June 1987), 46.*
11. *ISO/TC35/SC12/WG5, Working Group for Guidance on Levels of Contamination for Steel Surfaces before Application of Paints and Related Products.*
12. *M. Morcillo, J. Simancas, J.M. Bastidas, and S. Feliu, "Protectión Anticorrosiva de Estructuras de Auro Mediante Recubrimientos de Pintura. Estudios en Curso,"* Revista Iberoamericana de Corrosión y Protección *(Spanish) (Vol. 14, Special Issue, 1983), 297.*
13. *M. Morcillo, J. Simancas, J. Antuñano, and A. Monge, "Pinturas Marinas para Buques. Resultados de Investigaciones,"* Ingeniería Naval *(Spanish) (Vol. LVII, No. 653, 1989), 488.*
14. *U.R. Evans and C.A.J. Taylor, "Metal-Pigmented Paints for the Protection of Steel,"* Transactions of the Institute of Metal Finishing *(Vol. 39, 1962), 188.*

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